Section Life Cycle Management

Design for Environment

Functional Priorities in LCA and Design for Environment

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Abstract

Aim, Scope and Background. The interest in environmental questions has increased enormously during the last decade. Environmental protection has become an issue of strategic importance within the manufacturing industry and many companies are now working in the field of Design for Environment (DFE). The main purpose of DFE is to create products and services for achieving a sustainable society. Designers are widely believed to have a key role in adapting products to a sustainable society and one of the major instruments in the context of Design for Environment is Life Cycle Assessment (LCA). However, product development creates particular challenges for incorporating environmental issues that combine functional and environmental assessment. A natural and important part of product design is to define and analyse the functions of the product. Consequently, the functional unit in LCA is a core issue in DFE. Most recent research in DFE has focused on how to reduce the environmental impact of products throughout their life-cycle by addressing environmental aspects, while little attention has been given to the functionality of the product. Additionally, early product development phases, so called re-think phases, are considered to have the influence on major changes in products in general. These phases have thus the highest potential for changing products and product systems towards a sustainable development.

Main Features. This paper discusses an extended functional representation in design for environment methods to evaluate sustainable design solutions, especially in early (re-think) phases of product design. Based on engineering-design science and several case studies, a concept has been developed describing how functional preferences can be visualised in design for environment and product development. In addition, the functional unit in LCA is discussed. The concept is called Functional Profile (FP) and is additionally exemplified in a case study on radio equipment.

Discussion. The new functional characterisation concept helps identify functional priorities in design for environment. The Functional Profile is a structured, systematic and creative concept for identifying the necessary functions of a new product. The FP is envisioned to complement existing design for environment methods, not to replace them. Instead of being a product-development tool or method, the concept is an approach that increases understanding of inter-reactions between functional characteristics of products and their environmental characteristics, which furthermore facilitates trade-off decisions. One of the objectives behind the concept is to highlight the importance of balancing functional requirements and environmental impacts, presenting both the advantages and disadvantages of the product.

Outlook. A second paper will be produced to complement the functional-environmental characterisation concept in early product development phase, presenting the environmental characterisation part and illustrating correlations between the functional and environmental sides.

Keywords: Design for environment; functional product characterization; functional profile; functional unit; life cycle assessment; product development; product planning

Introduction

Environmental performance is highly dependent on the functionality and life cycle pattern of a product (Hanssen O-J 1996). Most recent environmentally-conscious design research focuses on how to reduce the environmental impact of products throughout their life-cycle by focusing on specific environmental aspects while keeping the functionality of the product unchanged. This approach is especially effective when re-designing products and can be observed in most DFE methods that have been developed, for example Life Cycle Assessment (LCA), Material Intensity Per Service Unit (MIPS), eco-guidelines, and checklists. However, considering sustainable solutions often demands radical changes and 're-thinking' of product systems, including potential changes both in functional and in environmental qualities.

One of the most commonly used DFE methods is LCA. An important part of the goal setting in LCA is to define the functional unit, which is supposed to represent the benefit of the product for the customer. The definition of the functional unit is based on the specified main function(s) of the system(s) under study. The functional unit is thus a relevant and well-defined strict measure of the function that the system delivers (user function) and is the basis for the analysis. In fact, the strictly defined functional unit is also considered to be a key element in the LCA methodology in the ISO 14040- series standards. Comparative assertions were seen as one of the main applications of the LCA methodology in the early 1990s and fear of misuse was the reason behind the development of a strict methodology in SETAC and later ISO. Consensus on statements such as 'only complete product systems may be compared' and 'the denominator shall be the function provided by the product system, not the product itself' became the platform for a methodology aiming at comparisons on equal and fair grounds.

However, the functional unit approach introduced allocation problems, and some early researchers used a multi-functional approach to overcome these whenever suitable (Lindfors 1995). That is, they used several functional units in parallel and compared product systems that fulfilled all functional units simultaneously. The basic concept of the functional unit was kept unchanged. This approach was similar but far from identical to the system boundary expansion approach of today. It was a suitable approach when various service systems were under study, but did not offer a solution to traditional comparative assertions of products although it showed that applications of LCA were far from restricted to traditional comparative assertions based on a single functional unit.

LCA methodology of today is capable of handling most allocation problems caused by the functional unit approach when reasonably homogeneous product systems are under study. Various types of 'product re-design' studies are likely to meet that requirement, but future challenges for LCA such as assessment of functional innovations and functional sales obviously will not. This is a huge problem in product development especially during 're-think' of product systems and modelling of new products. Arbitrary allocations may generate very misleading results. Thus, arbitrary allocations should be avoided in these cases and un-allocated system models should be applied.

One route which offers that option is to abandon the functional unit approach and report all functional qualities provided by the system instead. Obviously, results from such studies will show differences in eco-profiles and functional qualities simultaneously. Reporting must therefore be systematized and provide a visualization of similarities and differences for both eco-profiles and functional qualities. This paper focuses on the representation of functional qualities of products and product systems in early phases of product development, so called re-think phases.

1 Product Development and Design for Environment

Product development in industry today is a multi-facetted activity, often characterised by a large organizational structure, the involvement of many people, and a multitude of disciplines such as design, research, marketing, production and management. In order to achieve environmental-product improvements, DFE must adapt to, and become a natural part of, the product-development process, preferably as early in the process as possible. Early product development phases are widely believed to have the most influence on defining environmental aspects of products; see for example (Bhamra et al. 1999, Fiksel 1996, Luttropp et al. 1999, US Congress 1992).

Fig. 1 shows a simple model of the product-development process, concentrating on the paradox between design freedom and defining knowledge and data of the forthcoming product. Focusing on the increasing product knowledge and reducing design freedom over time, the design process can be represented by the curves according to the diagram. When designing a completely new product, at the outset the knowledge of the new product is small but the freedom is almost total, as nothing is established. This part is quite close to the design core, featuring a considerable amount of design freedom and little design restriction by known or determined features of the product to come, referred to as early product design phases. The process starts with a need to be fulfilled, or with new technology to apply, and the goal is to find design concepts for a product or component that satisfies these. Information about the product increases as the product develops, but at the cost of design freedom. A basic dilemma is that sustainable solutions often demand radical changes and 're-think' of product systems, and therefore rely mainly on decisions in early product development phases. At this point there is very little firm information about the new product, which means that quantitative methods would be difficult to apply, as they are data-intensive. Consequently, few environmentally-oriented design methods are available.

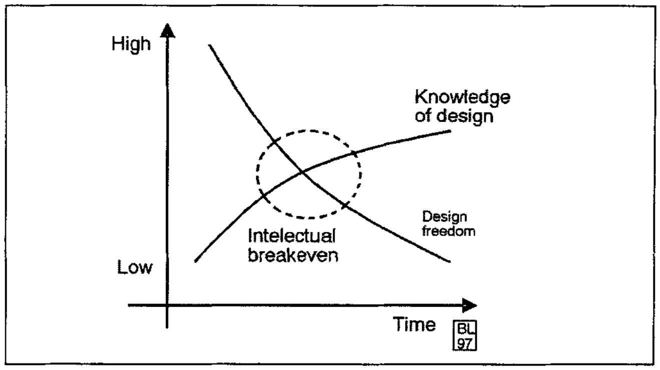

Fig. 1: Knowledge and design freedom in the product development process

When reaching some kind of intellectual breakeven, a concept of the new product is normally established. By the end of the process, the knowledge of the product is greatest, but the possibilities for changing the design are small. Global design decisions are already taken and only minor changes can be made, which implies that only re-design and small changes can be made. Retrospective LCAs or MIPS (Material Intensity Per Service unit) calculations requiring quantitative data can be performed. These stages are referred to as late product design phases.

1.1 The environment as a part of product development

Though environmental issues are important and ought to be adequately implemented, time constraints and deadlines in the real design world dictate that environmental issues cannot consume too much of the product development and design process time budget. In general, products are designed from a list of requirements, consisting of one or two main functions and several constraints. Very few products, principles or functions can be expressed using a single criterion, even if it is the main product function; other aspects like cost, physical lifetime and aesthetics are important factors underpinning customer preferences (Luttropp and Lagerstedt 1999). Most DFE methods are, however, based on one single condition (the main function). This has resulted in the comparison of dissimilar concepts and products, which ultimately affects the nature of conclusions regarding the actual environmental performance of products. For example,

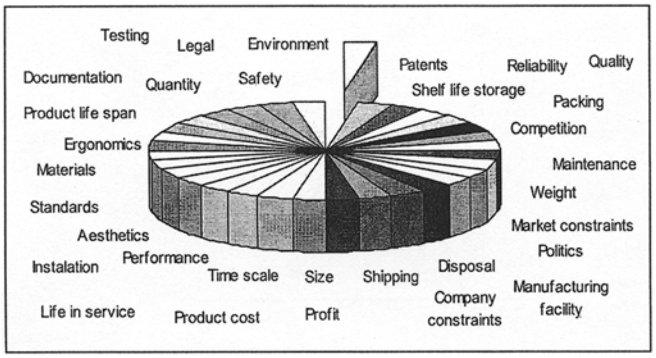

Fig. 2: Representation of all the demands that must be addressed in product development (Luttropp 1999)

advanced vehicles with better fuel economy can only, effectively, lower fuel consumption if they displace conventional, less fuel-efficient vehicles on the market. For this to happen, consumers must perceive them as possessing at least equivalent or equally attractive other performance parameters, such as safety, size, power, and price (MacLean and Lave 2000).

To achieve a more realistic evaluation, it is important to consider a set of core criteria in addition to the main function, keeping in mind, however, that environmental matters are not given top priority by designers. This situation can best be illustrated using a pie chart, where every piece of the pie represents an important design task (**Fig. 2**) (Luttropp 1999). In this respect, design for environment means taking environmental issues into account without compromising the other demands on the product, and design solutions must seek a balance among all the competing requirements.

1.2 Functional priorities in design for environment

To achieve a sustainable society, products must be environmentally adapted but at the same time they must also function well and be commercially viable, meaning that there has to be a balance between 'environmental cost' and 'functional income'. This situation can be compared with a financial balance sheet, where balance is sought between the income and the cost sides for a particular product in monetary terms. Taking the analogy further, eco-design establishes a balance between the income side (environmental impact) and the cost side (customer benefit) of the product (thereby explaining environmental cost and functional income in **Fig. 3**). (Lagerstedt 2000)

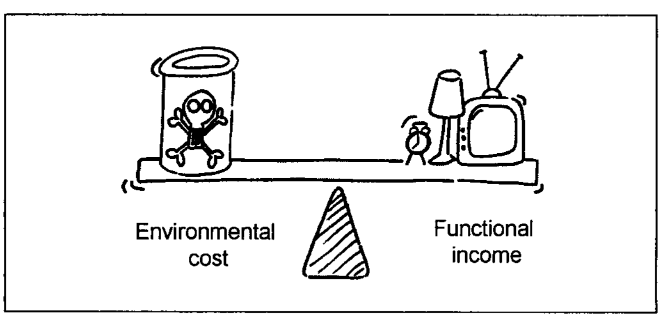

Fig. 3: Balancing environmental cost with functional Income (Lagerstedt 2000)

Various attempts at increasing the influence of customer demands in LCA have been undertaken using QFD, for example with 'Quality and Environment Function Deployment (QEFD)'. QEFD is described by Olesen as a method focusing on the design task by early observation and identification of the stakeholders' reactions to the quality and environmental properties of the product. The stakeholders who have greatest influence on buying decisions are selected and interviewed with regard to a reference product, and an LCA is performed concurrently. (Olesen 1997)

Similarly Masui and Zhang used QFD to enhance customer representation in design for environment; see Green Quality Function Deployment-II (GQFD-II) (Masui et. al 2000), and QFD for Environment (QFDE) (Zhang et al. 1998).

Dannheim et al. introduced some specific QFD matrices (QFDM) to relate environmental requirements to market and technical requirements. The matrix had a special focus on market-related products and was used to identify and classify erroneous human behaviour with respect to the environment during analysis in the usage phase. Weighting the interrelation and relative importance of requirements and product properties within the QFM methodology facilitates the task of finding a trade-off between conflicting requirements. (Dannheim et al. 1998)

Although these concepts do take the voice of the customer (VOC) into account, the information is presented on a detailed level, indicating progression beyond the early design phases characterised by 're-think'. Hence QFD only supports DFE in detailed phases of designing, characterised by 're-design' and minor improvements. Moreover, these approaches depict market and customer requirements as well as human behaviour, and they are rather elaborate and presume that the customer is always 'right', having the best knowledge of the product. But users cannot anticipate the potential of new technology. Reliance on VOC alone to represent functional preferences is therefore fraught with uncertainty. (Lagerstedt 2000)

2 Functional Profile

In an effort to achieve closer alignment with the functional requirements and properties of a product while performing design for environment, Luttropp and Lagerstedt proposed the use of a Functional Profile (Luttropp and Lagerstedt 1999). The specific objective of this concept is to expand the functional representation of products within a design-for-environment context, especially in early product development phases when major decisions are still at stake. A key element of the Functional Profile is to describe and evaluate properties that are associated with product functionality and commercial viability. Instead of being a product-development tool or method, the concept is an approach that establishes a platform for including functional requirements (properties functionally characterising a product) in design for environment. The concept provides a compass bearing, showing the direction to focus on, rather than being overly precise. In other words, instead of painting a detailed quantitative picture of the problem, the concept is qualitative and pragmatic. The Functional Profile is based on criteria relating to user benefit, influenced by Value Analysis (VA), Quality Function Deployment (QFD), and Kano Analysis (KA) approaches (see Miles 1972 and Clausing 1994).

Value Analyse (VA), which forms the basis for the Functional Profile approach, is a concept used for evaluating the functions of a product in respect to its monetary costs. VA is a structured, systematic and creative method for obtaining the necessary functions of a product at a lower financial cost. The concept emerged from rationalising philosophies in the USA in the mid-20th century and is based on numerous well-known methods and techniques for cost reduction. Traditional rationalising (cost reduction) philosophies ask basically the question: How could we manufacture this product at a lower cost? (Miles 1972). Value Analysis attempts to turn this somewhat defensive and negative viewpoint into a more positive and proactive approach by establishing a value for the product, which strongly supports the most important functions. From a user's / consumer's perspective, value has been defined as the lowest price to have to pay at a given time and place to fulfil a required function or service with a certain level of quality. As VA is a qualitative discipline, practical training is very important. Being qualitative, it should therefore be regarded as more of a guiding philosophy than a fixed method or technique. Today, however, VA is not used in DFE. But incorporating VA into DFE would allow DFE to 're-think' product and product systems in a more constructive way, commencing from the functionality of the product and then estimating the lowest environmental cost for achieving these, instead of the opposite. The Functional Profile, therefore, does not follow the traditional focus on the reduction of environmental stresses embodied in the question: How can we reduce the environmental impact of the product? Instead, it takes another approach and asks: What are the functional priorities of the product and what is the lowest environmental cost we incur while obtaining them? As with VA, the Functional Profile also strives to achieve the 'right' quality (not too much, not too little), striving to achieve it at as low a cost to the environment as possible.

In QFD, customer needs, desires and requirements are identified, evaluated and characterised into different categories, building a picture of the customers. These aspects are also included in the FP, although customer satisfaction or preference within the FP is not solely based on what the customers want. The FP also addresses other important aspects of the product such as environmental issues, even though this may not be a customer consideration. Hence, the FP is not based on a customer survey. Instead, the concept asks the designers themselves to put the product in the context of the user.

A model of customer satisfaction often used in QFD is the Kano model developed by Prof. N. Kano in the early 1980s, (Ullman 1997). KA uses a diagram for characterising customer needs. Customer needs can be divided into three principal categories; must-have, linear satisfier and delighter. KA has exerted an influence on the FP by facilitating the evaluation of all the various relevant functions with customer satisfaction levels. The *must-have* requirements represent product features that the customer expects to receive. When this product need is not adequately addressed, the customer experiences dissatisfaction. Take the example of a motor vehicle, where the customer simply expects the paint to maintain its appearance and accepts it while it continues to do so, showing little increase in satisfaction. However, should the paint fade, the customer would quickly become dissatisfied. The second type of need, the *linear satisfier*, is characterised by the relationship - the better the fulfilment of the need, the greater the customer satisfaction. A simple example would be fuel consumption, where the customer expects to achieve an average fuel consumption figure, but becomes increasingly satisfied as the distance travelled per litre of fuel increases. The third type of need, the *delighter*, is typically something not even expected by the customer; therefore its absence causes no customer dissatisfaction. Take, for example, when mobile phones were new on the market. Being able to choose different ringing signals can be seen as a delighter at the time, as this was not included in customer expectations. Discovering the extra signals was able to contribute to customer enjoyment (delight).

Additionally to the contribution from the literature, several case studies were performed enhancing and testing the functional profile concept. A case study on functional priorities looking at customer contra designer preferences was undertaken in the Stockholm area of Sweden in late 1998 and early 1999 (Lagerstedt and Luttropp 1999). One part of the project was undertaken as a master's thesis at the Royal Institute of Technology, Stockholm (KTH), and involved performing an LCA on two radio systems (Book and Cobdal 1999). The other part of the project (this specific case study) investigated measurements of customer benefits, and representations of functional priorities in intermediate design phases. Customer preferences for functional requirements were investigated through interviews and inquiries. In addition to the interviews, designers of similar radio equipment were interviewed to provide a comparison of customer and designer requirements for the radios. Although this study focused on one product only, it still showed important facts enhancing the FP, allowing it to be used for screening general functional properties in early design phases.

The second case study investigates company internal communication in design for environment and is based on a survey with two companies in German and Swedish industry. The survey focused on experiences of DFE and communication and transformation of environmental information from environmental experts through the product development organisation. An interesting observation was that most people from the management believed that environmental issues should be concrete, measurable, and not take too much space in the product specification. On the one hand, the designers wanted some simple rules of thumb adapted to the daily life of the designer i.e. information that is easy to understand and fast to read, and as far as possible can give feedback on changes due to environmental demands. On the other hand, designers participating in the case study expressed the wish that the functional profile could be used as a pedagogical tool to describe the picture in the back of their mind and to visualise priorities. (Lagerstedt and Grüner 2000)

The functional profile represents the total product benefit and takes user, society and company interests into account concurrently. More specifically, one can say that the functional profile is a representation of the designer's product responsibility to the users, the society and the company. Primarily this is not a full representation of what customers, society and the company want, but a characterisation of the designer's responsibility areas from a product perspective.

2.1 The functional profile: Creation and application

The Functional Profile describes how the product is functionally characterised by evaluating properties associated with product functionality and commercial viability. The profile is composed of (a) a functional description and (b) a set of functional categories. The main function of the product is represented in the functional description, and secondary functions are represented in the functional categories. The functional categories consist of eight parts, although the number of categories has changed along the way. It must be stated that this is not likely to be the final version of the concept, as new knowledge continues to refine the Functional Profile. Since the contribution of knowledge is low in early phases of design (see Fig.1), the Functional Profile only includes a few general functional categories. It is believed that the capacity of the short-term memory is effectively limited to seven chunks of information (plus or minus two), which was first described by Miller (1956) in a paper titled 'The Magical Number Seven, Plus or Minus Two', (Ullman 1997). That is, a person can only deal with seven, plus or minus two, pieces of information in her/his mind (short-term memory) at one time, which also supports the idea of a few general categories. These key categories represent the central functional priorities in the early phases of design (general properties identified as fundamental for product function and sales success). Table 1 shows a possible set of functional categories included in the Functional Profile. These initial characteristics will then guide the designer in attempts to achieve the specific properties creating as low an environmental impact as possible: finding design strategies in the early phases of DFE. Depending on the type of product being evaluated, categories can be added or removed. Broadly speaking, these categories characterise the functions of the product in the early stages of the product-development process, and the value of each category is based on the purpose of the product and field of application. It is, therefore, important to estimate these values independently of any imagined environmental impacts. Even from an environmental point of view, it is important that the most significant functions are fulfilled, as a product that does not work or sell will be of no use to anyone, and therefore incapable of justifying its existence, no matter how low the environmental impact. A major factor when considering functional priorities is to keep the user in mind. Even though it is too early to perform customer surveys to establish a detailed picture of the customers, it is still useful to utilise experience gained from earlier projects, putting oneself in the role of the user.

Functional description. The functional description describes the main function of the product, which is the most important rationale for the product. In the example of a car, it is to convey occupants from point A to point B; for a coffee machine it is to make coffee. This description is mainly used to keep the most important function in mind, highlighting it as the central task for the product. The main function is preferably described in a single sentence (see the top of Table 1).

Functional Categories. Customers do not usually choose to buy products based solely on the main function. It is often the secondary functions that satisfy customer desire, such as price and aesthetics. The most important properties are identified and evaluated, which is a simple description of the

Table 1: The Functional Profile (Lagerstedt 2003)

Functional Description ....

Functional Category	Value (0–10)	Comment
A) Physical Lifetime		
B) Usetime		
C) Reliability		
D) Safety		
E) Human/machine interaction		
F) Economics		
G) Technical flexibility		
H) Environmental demand		

benefits of the product to the customer, and why the product is expected to attract customers (**Table 1**).

It is important to put the soon-to-be-developed product into its correct user-context, in other words, envisaging the purpose of the product and deciding how important the different functional categories are for the user concerned. Every functional category is qualitatively evaluated, given a value of between 0 and 10, indicating its importance. The value is entered into the field after each category (column two in Table 1). Moreover, these values are based on actual values rather than set points. Information from earlier projects and products contribute to the evaluation of the categories, but the information is then aggregated into early design. Furthermore, the evaluation is based on the experiences of product-development personnel, indicating what the most important functional categories are (the criteria with the highest values).

Zero (0) implies a minimal benefit of the category to the user, and as the value increases so does the importance to the product performance. In other words, the higher the value a category is assigned, the more important it is for fulfilling this property, though it does not rank the properties against each other. Values around five indicate that the properties have a significant influence, while functional categories assigned ten dominate the eventual appearance of the product. Despite the fact that a high value signifies a greater functional importance for the product characteristics, a high value such as 10 does not signify a winner. On the other hand, a property category assigned a low value is also interesting, as it means that it will be easy to reduce the resources needed, and therefore involves a potential advantage for the environment without the need for a trade-off. Furthermore, it is preferable to provide a comment to accompany the figure allocated to the category, thereby helping to recall what decisions the value was based on (column three in Table 1).

The following question can be asked when determining the value of each property, thereby helping the designer assign a reasonable value to the functional category: *Will the product sell and work as planned even if this functional category is not completely fulfilled?* If the answer to this question is *Yes, certainly, without any problem*, this category ought to be assigned a low value (0, 1 or 2).

If, on the other hand, the answer is somewhat more vague, the category ought to be assigned a value around 5. A strongly negative answer, such as, *No, the product will definitely not work properly if this functional category is not completely fulfilled*, is assigned a value around 10.

2.2 The functional profile on radio equipment

To illustrate the use of the FP and to compare it with the FU in LCA, a case study on radio equipment for police and firemen has been used. In the LCA discussed in the case study, the FU was expressed as 'the use of mobile radio equipment during one year' (Book and Cobdal 1999). This description does not consider functional priorities and customer-oriented issues, such as how often the radio is to be used, its lifetime, price and reliability.

The FP provides a clearer picture of several customer-oriented properties. The functional description, describing the main function, is expressed by 'to communicate talk'. Using the FP and compiling several secondary functions, in the early design phases is shown in **Table 2**.

Table 2: The functional profile for radio equipment

Functional Description: to communicate speech

Functional Category	Value (0–10)	Comment
A) Physical Lifetime	8	About 30 years
B) Usetime	9	Used continually until it breaks
C) Reliability	10	Crucial for its existence
D) Safety	2	A product failure doesn't hurt the user itself
E) Human/machine interaction	4	Ergonomics important, aesthetics minor
F) Economics	0	Minor
G) Technical flexibility	7	Important, upgraded repeatedly
H) Environmental demand	3	Presently low

The FP in Table 2 indicates the following: the radio is used continually, until it is almost torn apart (upgraded repeatedly); lifetime is long (about 30 years), it is subjected to very frequent use (24 hours a day). Good ergonomics, easy understanding and operation of the radio are therefore important properties, but aesthetics is of minor importance. Technical flexibility should be high, requiring good in-use flexibility and service adaptation. Environmental demands are presently low; extended producer's responsibility has to be taken into account and it could be guaranteed that some of the parts would be recycled. The product price is of minor importance. Safety is considered as having low importance; a product failure would not hurt the user. However, as lives rely on this product, reliability is without a doubt the most important criterion. In other words, getting the main function right is top priority.

As the FP presents a more enhanced picture of the functional requirements in the early phases of design than for example the FU in LCA does, it establishes a more useful functional basis for DFE. In other words, it would be possible to environmentally adapt products based on these functional facts, in order to improve their contribution to achieving a sustainable society.

2.3 The functional profile in product development

As the requirements and characteristics of a new product change with their progression along the product-development process, so does the appearance of the Functional Profile, as illustrated in Fig. 1. The Functional Profile shown in Table 1 only illustrates the character of the Functional Profile in early phases of product development process, when needs are established and concepts generated. Later on when a concept is chosen and developed, more information about the product becomes available. Proceeding from the highest ranked criteria in the Functional Profile in the early phases, a more detailed description of the requirements is needed to further develop the product concept selected. In other words, a more detailed description of the strongest requirements in the Functional Profile are further evolved, supplying designers with a more detailed picture of the customer (**Fig. 4**). The intermediate phase, which takes more specific customer preferences into account (possibly based on a customer survey and/or market analysis), is used to map these customer requirements in the FP. Single capital letters (A-H) denote the various categories in the early design phases, where for example for FP (A) Physical lifetime, (B) Use-time, (C) Reliability and (D) is Safety. In the more detailed description, each requirement is named after the main property in the aggregated profile. In the example of the radio system for firemen, more detailed requirements relating to (D) Reliability, are labelled: (D1) Volume (sound quality), (D2) Range, (D3) Set-up time, (D4) Ease of operation. In the detailed phase, the property-specific phase, the Functional Profile from earlier phases is further enhanced, providing an even more detailed picture of the product. The Functional Profile in this phase is likely to be the product specification itself, forming a basis for the prototype and final product.

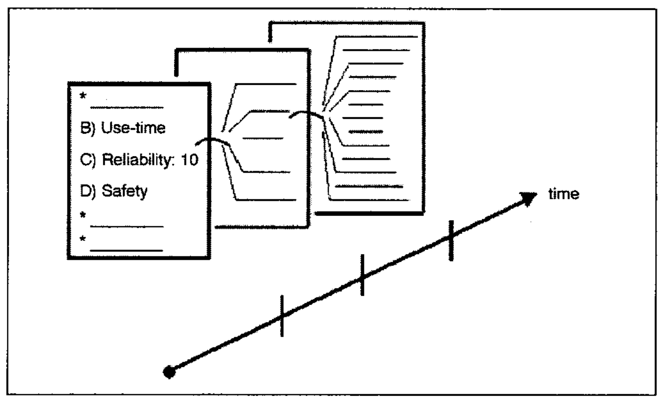

Fig. 4: The functional profile developing from early design phases through mid product-development process into later phases (Lagerstedt 2003)

3 Discussion

In the early phases of design of a completely new product, what is needed is an easily-understood, non-quantitative description of the general functional and environmental requirements, thereby creating a compass bearing for design. Since little is known and finalised about the new product at the time, it should be helpful to use a FP to describe the functionality of the product. It must furthermore be stated that the whole concept is simple and focuses on the product in use-phase, or more specifically, the early design expectations on the soon-to-be-developed product. Moreover, it concentrates on the level of the whole system and does not primarily take into account detailed levels such as part level. However, it requires basic design knowledge, creativity and a good understanding of the product from a user's point of view.

As well as reducing the environmental impact, it ought to be possible to improve the functional side of the product, thereby increasing the functional income, but still achieving design for sustainability. Materials and processes related to the most important criteria in the Functional Profile should not be replaced without justifiable reasons. In other words, materials and processes, strongly linked to high-priority customer demands, should be considered very carefully before they are removed or replaced, even though they may have a high environmental impact, since they are doing a very good job. This relates especially to those materials and processes associated with life-saving products, such as halon-based fire-fighting equipment or respirators. The message being conveyed here is that these types of products may justifiably be more environmentally unfriendly than luxury products, thus indicated in the FP. Put another way, criteria with low values are not very important for the functional performance of the product, thereby allowing the preferable option of selecting more 'environmentally friendly' materials and processes in production, even where they won't completely fulfil the functional constraints. For example, when designing disposable products, lifetime and frequency criteria have low values, and therefore it is preferable to use recyclable materials in their production.

We believe that this will give rise to many new challenges for decision-makers and to some extent, take LCA modelling back to reality. This will also enable models to handle life-cycle costs and social impacts, for example, and provide an input to multi-criteria decision-making.

4 Future Research

The concept of the Functional Profile has been the first step in finding links between functional criteria and environmental impact of products. The second step aimed at establishing a balance between Functional Profile and significant environmental impacts in early product development phases. This research was carried out in co-operation with CADlab, Massachusetts Institute of Technology (MIT), testing already established concepts.

One interesting direction of future research would be to gather a designer's committee and representatives from users and society to functionally evaluate a large number of products. Additionally, user behaviour could be studied and incorporated in the functional profiles.

Another relevant question to investigate is product development trade-off situations. That is, to what extent product attributes in the characterisation framework are open (or not) for tradeoffs. In the conceptual design phase, some high-level attributes are often locked into specific values from the very beginning in the product planning stage. For example, if a two-year contract with a supplier has been signed, this might lock the trade-off on the specific components from this supplier. Such constraints may result from company culture, supply chain, or manufacturing constraints. Early identification and declaration on open and locked parameters for trade-off saves time and money. In fact, these issues incorporate true design problems, but they are also a key to sustainable product design in industry.

Third, product classification according to common functional patterns is being explored. Even though every product is unique, the general goal of product classification is to identify distinct common patterns among a group of products and thereby take full advantage of the shared characteristics, to develop generic guidelines for groups of products, for example. The classification criteria can be based on different functional criteria, for example, hobby or professional use and industrial or consumer products.

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